

California Energy Commission

FINAL REPORT

Codes and Standards Enhancement – Quality Demonstration Program

California Energy Commission

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The Energy Research and Development Division strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

Energy Research and Development Division funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Codes and Standards Enhancement – Quality Demonstration Program is the final report for the project (contract number PIR 12-027 conducted by University of California, Davis, California Lighting Technology Center. The information from this project contributes to Energy Research and Development Division's Buildings End-Use Energy Efficiency Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

The codes and standards Enhancement-Quality Demonstration Program establishes guidelines to help standardize the demonstration of energy-efficient building technologies to more usefully inform California codes and standards activities. The program bridges the gap between small, pilot scale technology demonstrations/assessments and broad, market transformation programs currently supported by the California Energy Commission and other stakeholders.

The Codes and Standards Enhancement-Quality Demonstration Program is a sustaining, Energy Commission program that optimizes and leverages its funding to support technology development and codes and standards enhancements. Assessments conducted under this program produce complete and detailed technology reports that may be used by the Energy Commission, utilities and other stakeholders as part of their codes and standards enhancement initiatives.

The guidelines and procedures contained in this program are intended for use by any project team wishing to conduct a robust and well-documented technology demonstration. In addition to providing this resource, the program directly supports identification, selection, installation, and performance assessments of energy-efficient building technologies ready for current or near-term inclusion in California codes and standards initiatives.

Keywords: Assessments, California Energy Commission, CASE, CASE-QDP, demonstration, efficiency, emerging technology, energy efficiency, technology

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EXECUTIVE SUMMARY

Background

The California Energy Commission Electric Program Investment Charge program issues public funding for technology research, development and demonstration. These funds provide a valuable mechanism for research teams to transfer energy efficiency ideas, designs and prototypes into real-world energy saving products. These activities form a foundational building block in California's efforts to achieve its energy reduction goals.

Technology assessment, while highly successful in improving market awareness for emerging energy-efficient technologies, has not universally been able to provide the robust data sets required for these assessments to feed statewide codes and standards enhancement activities. Codes and Standards enhancement activities can include technology evaluations and developing standards to implement technologies. This gap in the case study and demonstration process has been acknowledged by the codes and standards community and a call for a unifying program is addressed with the research results contained in this report.

Project Purpose

This project developed a detailed assessment program to support demonstrating California Energy Commission sponsored building efficiency technologies. The program developed is referenced as the codes and standards Enhancement Quality Demonstration Program. The program lifts the burden of how to provide comparable technology assessment results between researchers by standardizing the process for all codes and standards enhancement initiatives. To do this, the program compiles published literature, best practices, and "common sense" recommendations for technology assessments into one referenceable document.

Technology assessments executed according to the program guidelines deliver a complete, robust data set on the demonstrated technology-a data set able to educate, guide and affect California codes and standards enhancement activities. This program achieves these goals through four key activities:

- Assessment of primary codes and standards-ready building technologies and appropriate applications for installation
- Market and economic assessment of emerging technologies that do not currently have funding available to support a codes and standards enhancement -quality measurement and verification component; a component necessary for inclusion of the assessment in future codes and standards activities
- Demonstration of technology in the field to gather technology performance information and end user acceptance
- Postassessment verification and analysis of key projects to verify estimated and/or demonstrated performance, energy savings, and carbon savings.

The project established a solid programmatic framework for the program to operate beyond the development phase. To do this, the research team a) demonstrated the viability and success of the program through multiple assessment projects including lighting, daylighting, heating, ventilation, and air conditioning, and other energy efficiency technologies; b) verified and documented postassessment performance; and c) delivered energy, market and economic analyses on all technologies to the California Energy Commission and other codes and standards stakeholders for use in the future iterations of codes and standards enhancement activities.

The initial concept of the program was circulated by the research team to the technical advisory group which consisted of representatives from municipal utilities, educational institutions, investor owned utilities, energy consultants, and the California Air Resources Board. This group provided input into key questions and ongoing reviews of the program use by the research team to “fine tune” the demonstration process and associated program manual.

Project Results and Benefits

Throughout this research, the emerging technologies that codes and standards entities are interested in evaluating is to understand if these codes and standards have evolved and are ready to be included in their programs. Best practices for how to conduct a robust, repeatable technology evaluation, however, remains focused on four key areas:

- Market and economic analysis
- Assessment methods and tools
- Field implementation
- Project documentation

The cross-section of outcomes for the five assessments conducted using the method provided in the program manual showed that both technologies ready-for-inclusion and technologies not-ready-for-inclusion in codes and standards enhancement initiatives can be assessed equally by this approach with usable outcomes. For each technology type, the demonstration activity followed the same market/economic analysis, metering and verification methods, field installation practices, and reporting.

Each demonstration using the program manual pointed to nuanced areas in the demonstration process that required more detailed guidance beyond the initial draft. These lessons were incorporated into the final version of the program manual for use in the program.

Activities that required ensuring the successful adoption and use of the program include outreach and advocacy to create awareness of the program; continued use of the program by the research team; and evaluating future research needs specific to the codes and standards stakeholder community.

To promote and gather feedback on the program and manual, the research team is using the CLTC website and newsletter, and the California Energy Commission's Online Resource Center. Additional advocacy work will be focused on encouraging the adoption of the program manual as a mandatory part of lighting stakeholder's demonstration activities. Key lighting stakeholders include, but are not limited to, the California Energy Commission's Building Energy Efficiency Standards team, the California Energy Commission's Appliance Efficiency Regulations team, the California Public Utility Commission, the U.S. Department of Energy, California investor-owned utilities, municipal utilities, and manufacturers of emerging technologies conducting field assessments.

CHAPTER 1:

Introduction and Background

The California Energy Commission Electric Program Investment Charge program provides public funding for technology research, development and demonstration. Funds provide a valuable mechanism for research teams to transfer energy efficiency ideas, designs and prototypes into real-world energy saving products. These activities form a foundational building block in California's efforts to achieve its energy reduction goals. In past years, however, technology demonstration efforts, while highly successful in improving market awareness for emerging energy-efficient technology, have not universally been able to provide the robust data sets required for these assessments to feed statewide codes and standards enhancement activities. This demonstration gap has been acknowledged by others in the codes and standards community.

The Codes and Standards Enhancement-Quality Demonstration Program (CASE-QDP) establishes guidelines to help standardize the demonstration of energy-efficient building technologies to more usefully educate and guide California codes and standards activities. The CASE-QDP bridges the gap between small, pilot-scale technology assessments and broad, market transformation programs supported by the Energy Commission and other stakeholders.

Assessments conducted under this program produce complete and detailed technology reports that may be used by the Energy Commission, utilities and other stakeholders as part of their codes and standards enhancement initiatives. The CASE-QDP is a sustaining, Energy Commission program that optimizes and leverages its funding to support technology development and codes and standards enhancements.

The guidelines and procedures contained in this program are intended for use by any project team wishing to conduct a robust and well-documented technology demonstration.

CHAPTER 2:

CASE-QDP Development

Developing the CASE-QDP relied on an iterative, industry-based approach. The initial concept of the program was circulated by the research team to the Technical Advisory Group (TAG) which consisted of representatives from municipal utilities, educational institutions, investor owned utilities, energy consultants, and the California Air Resources Board. This group provided input into key questions and ongoing reviews of the program use by the research team to “fine tune” the demonstration process and associated program manual. Each stage of the CASE-QDP development is highlighted in this section.

Program Concept

The CASE-QDP concept is based on the principle of accurate, repeatable measurement and verification of technology performance. The process of producing a quality demonstration consists of four key steps:

- Market and economic analysis
- Assessment methods and tools
- Conducting a study
- Project documentation

Market and Economic Analysis

Market and economic analysis is a key element of technology demonstration projects. By understanding the market, program participants can more effectively estimate the savings impacts of a demonstration measure. Economic analysis often depends on information gathered during the market assessment, and this analysis is revisited during postretrofit project and reporting activities. When conducted at the earliest stages of a demonstration project, these analyses can focus selection of technologies, host sites, or other project parameters, to ensure the most effective outcomes.

Assessment Methods and Tools

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) publishes a guideline for *Measurement of Energy and Demand Savings* (ASHRAE Guideline 14-2002), which covers most aspects of project assessment methods, measurements and tools applicable to the program. This program borrows heavily from that guideline for measurement and verification (M&V). Where applicable, demonstration teams should reference detailed procedures contained in that document, in addition to various industry accepted standard test methods.

Conducting a Study

Technology assessments conducted in CASE-QDP produce complete and detailed technology reports that may be used by the Energy Commission, utilities and other stakeholders as part of their CASE initiatives. The design, implementation and documentation requirements for a CASE quality demonstration project are provided in the program manual, including recommendations for selecting technologies and sites; assessment requirements for existing and proposed measures and technology installation considerations. In general, designing and implementing a study will include:

1. Pre-demonstration market and economic evaluation
2. Site selection
3. Technology selection
4. Assessment plan development
5. Benchmarking
6. Technology installation
7. Post-retrofit measurement and evaluation
8. Outcomes and reporting

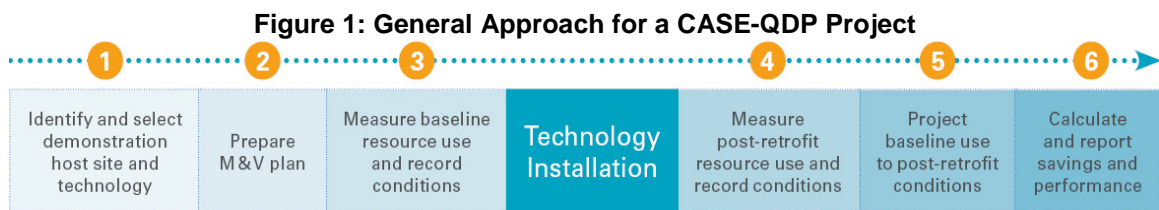
Project Documentation

Final demonstration reports are meant to capture the relevant details and analysis of the demonstration concisely. Standard report sections include an executive summary, a summary of the incumbent installation, retrofit technologies, market analysis, and an identification of the key stakeholders. Information relevant to the sections should be included in appendices. In addition, site specific test plans and technical specifications of the demonstration technology is required for a CASE-QDP report.

CASE-QDP Program Manual Development

To compile the key steps into one referenceable resource, the research team developed a CASE-QDP program manual. The program manual establishes the necessary, universal methodology required to produce meaningful datasets from emerging technology assessments. The guidelines and procedures contained in the CASE-QDP's program manual can be used by any project team in need of information on how to conduct a robust and well-documented technology demonstration.

There are six major components of a typical technology demonstration project, in addition to technology installation at the host site. These major program components are detailed in Figure 1 and included in the program manual.



In addition to defining a quality demonstration from start to finish, the CASE-QDP directly supports identification, selection, and installation and performance assessments of energy-efficient building technologies ready for current or near-term inclusion in California codes and standards initiatives. In this way, CASE-QDP bridges the gap between small, pilot-scale technology demonstrations/assessments and broad, market transformation programs (Figure 2).

Figure 2: Research, Demonstration and Commercialization Pipeline



Source: UCD – California Lighting Center

The program supports the evaluation of emerging technologies with the potential to improve the efficiency and performance of California buildings and appliances. The program manual provides the methods and procedures necessary to conduct meaningful technology assessments that usefully inform codes and standards activities. To achieve this objective, the program manual:

- Provides consistent methods and procedures for conducting technology assessments to ensure quality and useful demonstration results
- Provides standard requirements and templates for reporting outcomes that are synchronized to the needs of the codes and standards process.

The CASE-QDP program manual development was conducted in two major phases: the initial drafting phase and the use of the program manual in the field. After each phase, the program manual was circulated to the TAG for review and input on the program.

Phase I

The CASE-QDP program manual compiles emerging technology demonstration best practices, existing standards used in the field, and lessons learned from field assessments conducted by the research team. To leverage common practice and reduce redundancy in projects, the first draft was based on best practices defined in existing documentation. The technical advisory group reviewed the first draft of the program manual and added input according to the members experiences.

The final version of the first phase of the program manual guided five independent assessments of emerging technologies.

Phase II

The research team revised the program manual based on lessons learned during the program demonstration phase.

The research team executed five demonstration assessments using the Phase I of the program manual. Based on lessons learned in the execution of these assessments, the final program manual was revised to:

- Explicitly call attention to the effect of data logger memory length on the ability of the demonstration to gather uninterrupted data regardless of site restrictions for the ideal resolution of data.
- Include the option for side-by-side incumbent and emerging technologies operation to more accurately capture the energy savings attributed to the technology efficiency versus the user behavior and to better determine the variance in energy savings based on user behaviors.
- Investigate inherent differences in laboratory assessments versus field assessments to determine if a complementary program manual is necessary for laboratory assessments; or, determine whether to include specific guidance for laboratory assessments in this program manual.
- Include discussion of the pros and cons regarding installation labor payment and management. Potential benefits include streamlining the communication and demonstration chain of command to retain as much ownership of the demonstration as possible.
- Elaborate on the effect of the community on the technology demonstration.
- When a portion of a technology system can leverage preexisting components of incumbent system, include the end-of-life and maintenance impacts in the technology selection considerations.
- Add a subsection within the Technology Installation section addressing the commissioning process for typical emerging technology systems.
- Add a subsection within the Technology Installation section addressing troubleshooting to define the initial troubleshooting process for emerging technologies to reduce required site visits and the associated costs.

The final version of the program manual is provided in Appendix A.

CHAPTER 3:

Program Assessments

The research team conducted five technology assessments based on the guidelines established in the program manual to evaluate the effectiveness of the program manual in the field. A cross-section of multiple lighting, daylighting, heating, ventilation and air conditioning (HVAC), and natural-gas efficiency technologies that were ready for potential inclusion in future California codes and standards enhancement activities were selected.

Moreover, the research team conducted a post-assessment verification and analysis of key projects in California to verify estimated, demonstrated savings or both. A cross-section of lighting projects installed by California Advanced Lighting Control Training Program (CALCTP)-certified and uncertified installers were included to identify any economic, energy and performance impacts of this workforce education program.

Assessment Summary Results

The five assessments conducted using the methodology provided in the program manual showed technology ready for inclusion and technology not yet ready for inclusion in CASE initiatives can be assessed equally by this approach. Each demonstration followed an equivalent method to conduct market/economic analysis, metering and verification methods, field installation practices, and reporting.

Each assessment using the program manual pointed to areas that required more detailed guidance beyond the Phase I draft and these areas are provided in the following sections. Detailed information for each assessment can be found in Appendices B-F.

Residential LED Luminaires and Lamp Replacements

In California, about 90 percent of installed residential luminaires are considered low-efficacy under the *2013 Building Energy Efficiency Standards* (Title 24, Part 6). Low-efficacy lighting includes all types of incandescent and some types of fluorescent lighting. At the national level, about 65 percent of homes still use incandescent sources. Less than 1 percent use light-emitting diode (LED) replacement lamps and dedicated LED luminaires.

In 2012, the California Energy Commission published a *Voluntary California Quality Light-Emitting Diode Lamp Specification* to set a minimum specification for certain types of LED lamps intended for use in California. This specification is not mandatory, however, adoption is encouraged in an effort to increase energy savings and lighting quality for all Californians. The California Public Utility Commission (CPUC) has adopted this standard as the minimum performance specification for lamps receiving an incentive/rebate from a California investor-owned utility (IOU).

Project Purpose

This project demonstrated and evaluated the performance and cost-effectiveness of commercial-off-the-shelf (COTS) LED luminaires and LED pin and screw-base lamp replacements in a home. LED products are poised to replace fluorescent and incandescent sources for nearly all residential applications, and this research is intended to inform stakeholders on in-situ performance and consumer perceptions of the technology.

Project Approach

For this demonstration, the research team considered LED replacement lamps meeting California's 2013 residential energy efficiency standards. In addition, cost-effective products providing adequate light output for residential applications and meeting the Voluntary California Quality Light-Emitting Diode Lamp Specification were prioritized during the selection process.

The research team selected a multifamily, residential apartment complex for demonstration of selected products. The demonstration site consisted of 24 apartment units, each roughly 600 square feet in area. The research team completed site audits to identify the existing lighting systems and lighting needs. Using this information, the team designed and installed replacement LED solutions for the majority of living spaces within each apartment. Demonstrated products included medium, screw-base LED lamps (A lamps), tubular LED lamps (TLEDs) and GU-24 LED lamps.

In parallel with this work, the research team designed and deployed pre and postretrofit occupancy surveys and collected lighting energy and time-of-use data to estimate annual energy use and savings resulting from the project.

Project Results

Based on national residential lighting use studies, the research team estimates that by replacing traditional light sources in a typical U.S. residence homeowners can expect a simple payback of 3.2 years. Over a 15-year period, the incremental net present value of this project is estimated to be \$1,084. While demonstrated energy savings are significant compared to baseline systems, results in a multifamily scenario are cost-effective only under certain conditions. Homes where the existing annual lighting use intensity (kWh per square foot) is greater than about 0.25 results in a simple project payback of less than 15 years. Fifteen years represents a typical lighting project evaluation period. The site-specific combination of product costs and low lighting use levels result in an average project payback period of 14.7 years. Homeowners considering the switch from incandescent or CFL screw-base lamps only, based on outcomes of this demonstration and other published data, may expect a payback of two-four years. In addition, lighting use data also shows the space types in the home where lighting is used more frequently: the kitchen, living room and dining room. Focusing retrofits in these areas of the home will result in a more cost-effective lighting retrofit for the typical apartment resident.

Technology Development

Four-foot LED lamp replacement solutions that adhered to the residential lamp requirements of the project available for purchase at the time of this demonstration were minimal. In addition, the manufacturer of the selected product issued a recall for this lamp citing: electrical arcing may cause the lamp to overheat and melt, posing a burn hazard. Development of cost-effective, safe, four-foot LED replacement lamps that meet the California energy efficiency standards is recommended to increase market adoption of residential LED lamps. In addition, at the time of this demonstration, there were limited commercialized products available that met the project criteria for GU-24 sockets. Additional development of cost-effective GU-24 LED replacement lamps compliant with California energy efficiency standards is recommended to address the GU-24 sockets unique to California homes.

End-User Acceptance

Apart from technology availability and associated costs issues, LED replacement solutions were very well received by occupants participating in the project. When asked to identify the issue most bothersome to them about the new lighting system, 94 percent of respondents responded “nothing.”

The research team collected additional survey data to understand residential use patterns and identify areas most in need of lighting retrofits. Occupants were asked to rank the criteria most important to them when purchasing lighting products: lifetime, price, lighting color, light distribution, brightness, energy efficiency, lower energy bills and other. The top criterion selected was lifetime followed by lower energy bills suggesting that the long-life LED products were well-suited to residents' needs.

When asked which area of the apartment received the largest lighting improvement from the lighting retrofit, 75 percent of respondents replied the kitchen. The lighting use data indicates that the kitchen is also the space used most by occupants. Products developed specifically for high-traffic areas of the home such as the kitchen are expected to be well-received and improve market adoption of LED technology.

The complete project report is provided in Appendix B.

Innovative Occupancy Sensors for Outdoor Applications

California Legislature mandates a reduction in lighting energy use for commercial and residential sectors. Per Assembly Bill 1109 (Huffman, Chapter 534, Statutes of 2007), California must reduce its commercial outdoor lighting energy use by 25 percent between 2007 and 2018. This mandate is also addressed federally by the U.S. Environmental Protection Agency (EPA) greenhouse gas reduction goals (EPA-2009 GHG) goals.

Optimized lighting achieved using adaptive outdoor lighting systems has the potential to help reduce California outdoor lighting energy use. Adaptive outdoor lighting

systems provide the right amount of light when and where it is required, often leveraging environmental sensors to identify when and where it is necessary. Occupancy-based lighting controls are clearly shown to be an effective strategy to reduce energy waste and light pollution during long periods of inactivity generally associated with illuminated outdoor environments.

A key component to adaptive light systems is the sensor. However, existing passive infrared (PIR) sensors applied in outdoor applications are simply indoor devices transferred to the outdoor environment. Many of these sensors have a limited range of motion detection, usually up to distances equal to the mounting height of the sensor. While this detection range is effective for indoor applications, it is very limiting for outdoor applications, such as street lighting, which typically has much larger luminaire spacing and mounting heights. Moreover, traditional PIR sensors are often unable to accurately and consistently detect occupants moving at high speeds or under very hot or cold outdoor conditions. Commercialized sensors appropriate for detecting occupancy under such conditions are emerging as stand-alone devices or as part of networked lighting control systems or both.

Project Purpose

This research characterized the performance and reliability of innovative, outdoor occupancy sensors for street and parking applications. Research focuses on emerging, microwave-sensing technology and wireless network control systems, which have the potential to meet the requirements of hard-to-serve outdoor applications with tall pole heights and wide pole spacing.

Project Approach

This demonstration consisted of a series of laboratory and field evaluations to characterize sensor performance, quantify energy and other benefits, and understand additional technology development needs, if any, to ensure reliable sensor operation under outdoor conditions. The approach to demonstrate and evaluate the system was conducted in these steps: market analysis, potential economic impact analysis, demonstration site selection, technology selection, assessment plan development, technology implementation and pre- and postretrofit data collection. Outcomes are evaluated with respect to energy use, system performance, end-user feedback and cost-effectiveness.

Project Results

The sensor captured all occupants and vehicles. For slow-moving occupants and vehicles, the sensor, when set at low gain, detected objects at nearly 10 feet and 70 feet, respectively. When the sensitivity was increased to high, the sensor detection ranged improved to about 60 feet and 110 feet for pedestrians and cars, respectively. This represents a significant improvement over PIR technology, which has a maximum detection range of roughly 50 feet under ideal conditions.

In a commercial roadway setting, a system owner can expect to achieve between 3 percent and 15 percent energy savings as compared to a system without adaptive controls. Implementing more aggressive adaptive system settings such as shorter time-outs and implementing a high-end trim to reduce light levels during periods of occupancy results in higher savings. Tuning photocell settings can make a difference of up to 250 hours of system use per year, or roughly 6 percent per year variance, adding sizeable, unnecessary energy consumption to a site. Aggressive timeout settings for occupancy sensors are expected to yield additional energy savings without compromising safety. The research team recommends the manufacturer consider this feature for development in the next generation of its product.

Installation labor is one of the biggest costs associated with installing an adaptive lighting control system. Training of installers and contractors is advised as the emerging technologies differ from the traditional street lighting products. The research team recommends developing manufacturer installation manuals for adaptive systems to address expensive installation issues.

Regarding end-user acceptance of the deployed technology, demonstrating innovative occupancy sensors in the field provided a test bed to survey end-users regarding their satisfaction with static street lighting and adaptive street lighting systems. About 54.5 percent of the end-users surveyed use the space as drivers of motorized vehicles and 18.2 percent walk. Around 45 percent of respondents reported they are satisfied with the new lighting system for their tasks most frequently performed at the site. Forty-five percent of respondents reported they did not notice the adaptive control features of the demonstration site, they were satisfied with the adaptive system and they felt satisfied or highly satisfied with their feeling of safety while using the adaptive control system.

The complete project report is provided in Appendix C.

Fault Detection and Diagnosis

The *2006 California Commercial End-Use Survey* attributes roughly 29 percent of commercial electrical use to HVAC¹. The majority of HVAC units in California are packaged single-zone equipment of older vintages (2008 and older). Anecdotally, the majority of the small California commercial businesses do not perform periodic maintenance on HVAC systems. A solution to optimize their systems is necessary to improve the overall HVAC efficiency of California.

Promoting sustained, optimal performance in the world of HVAC presents big opportunities as well as monumental challenges in supporting California's efficiency goals. HVAC fault detection and diagnostics (FDD) is crucial to fully achieving sustained benefits of energy efficiency. FDD comprises a vast array of technologies that help

¹ <http://www.energy.ca.gov/ceus/>

identify maintenance or repair needs using measurements and software intelligence.² In this, FDD continues to have a key role, with ample room for advancement. The understanding of FDD technologies has come a long way but is still in the early stages. This project intends to explore select faults and FDD technologies applicable to a small commercial packaged rooftop unit (RTU) heat pump.

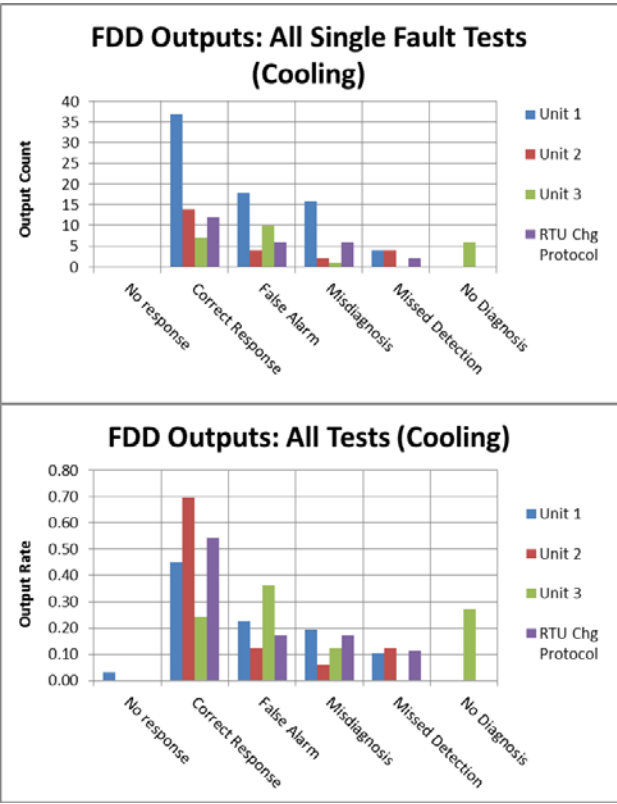
Overall, there exists a massive matrix of potential faults for the seemingly innocuous packaged rooftop unit air conditioner. These faults may exist in a variety of ways, made up of varying fault types, fault intensity/severity, fault combinations, system/component configurations, indoor/outdoor conditions, and others. This laboratory study focused on the economizer, charge and airflow faults, anchored to a typical 5 ton RTU heat pump, under outdoor design conditions representative of California climate zones. The research team subjected four FDD units and the RTU charge protocol to a series of laboratory tests. Economizers are electro-mechanical devices that act as damper vents to reduce energy consumption, and bring outside air when needed. The main areas for this study's findings include:

1. FDD performance for three units and RTU charge protocol under controlled, steady-state lab conditions under cooling mode operation.
2. FDD performance for one unit under controlled, steady-state lab conditions under heating mode operation.
3. FDD performance for one unit under economizer faults.
4. The impacts of several common faults in single and multiple-fault scenarios.

Generally, economizer FDD performance analysis is more binary, diagnosed or not diagnosed. For charge and airflow faults, a fault impact target must be set to frame the analysis. Figure 3 and Table 1 illustrate an example of FDD performance results for all cooling mode tests, with the fault impact target also indicated.

² https://engineering.purdue.edu/HVACFDD/pdfs/Workshop_on_FDD_for_RTUs_Presentations/RTU_FDD_Introduction-Braun.pdf

Figure 3: FDD Outputs: All Tests, Cooling Mode



Source: UCD – California Lighting Center

Table 1: FDD Outputs: All Tests, Cooling Mode

Description	FDD Test Unit	Number of Tests	Tests that Exceed Fault Threshold	Sum of Total Outputs	Output Category	Output Rate	Output Count
All Cooling Mode Tests	Unit 1	33	19	98	No response	0.03	3
					Correct Response	0.45	44
					False Alarm	0.22	22
					Misdiagnosis	0.19	19
					Missed Detection	0.10	10
					No Diagnosis	0.00	0
	Unit 2			33	No response	0.00	0
					Correct Response	0.70	23
					False Alarm	0.12	4
					Misdiagnosis	0.06	2
					Missed Detection	0.12	4
					No Diagnosis	0.00	0
	Unit 3			33	No response	0.00	0
					Correct Response	0.24	8
					False Alarm	0.36	12
					Misdiagnosis	0.12	4
					Missed Detection	0.00	0
					No Diagnosis	0.27	9
	RTU Chg Protocol			35	No response	0.00	0
					Correct Response	0.54	19
					False Alarm	0.17	6
					Misdiagnosis	0.17	6
					Missed Detection	0.11	4
					No Diagnosis	0.00	0
Established fault threshold for analysis: >10% % air-side or refrigerant-side cooling impact, >10% total power impact, or >10% high charge.							
For select tests at OD 115F, the OD temps slightly exceeded 115F, which caused FDD unit 2 to be prevented from issuing diagnostics. The temperature was overridden to 115F.							
For select OD restriction tests, unit 1 & 3 required overrides of high pressure readings to their max values.							

Source: UCD – California Lighting Center

The state of FDD technology today can assist in some key areas, but there are issues that reside outside the scope of FDD. It remains to be seen what the value of FDD benefits is, and how far it can potentially go. This project has generated raw outputs of FDD performance, but additional steps to value these outputs must be pursued.

At this stage, one cannot definitively assess what constitutes “good” FDD or “bad” FDD. The research team cautions to avoid the mindset of assuming that the goal of “good” FDD should be at/near 100 percent correct response count/rate (with 0% count/rate of other responses). This is an easy trap to fall into as it is an arbitrary, ideal notion, with no realistic foundation (this statement wouldn’t be made just as one would never make the statement that a “good” baseball player should be at or near a 100 percent batting average.)

The complete project report is provided in Appendix D.

Gas-Engine Heat Pumps

Buildings consume 70 percent of the electricity in the United States, 50 percent of which is used for commercial buildings. Heating, cooling and ventilation account for more than 35 percent of the annual primary energy consumption of commercial buildings in California (EIA 2012). Air conditioning is the largest contributor to peak electrical demand. Rooftop units are usually the largest connected load in a commercial building, and can account for more than 50 percent of the on-peak demand from these facilities.

California's electric grid is especially stressed during the summer when electricity generation requirements can be twice as high as other seasons. On the hottest summer days, air conditioning alone accounts for more than 30 percent of the peak demand on the statewide electric network (EIA 2014, Energy Commission 2006). Similar peaks in electricity demand are not observed in the winter because the majority of heating is achieved with natural gas.

Gas engine heat pumps (GEHP) can eliminate peak demand by producing the mechanical energy necessary to drive the vapor compression cycle on site from natural gas. Manufacturers claim the efficiency of a gas engine heat pump is similar to an electric heat pump when losses during electricity generation and transmission are considered. Since air-conditioning loads are a large fraction of statewide electricity demand, these systems can significantly reduce the impact of a building on the electric grid.

Project Purpose

This project characterized the performance and energy efficiency of an installed GEHP. The field performance of the GEHP was compared to the manufacturer's published performance data. Moreover, to provide a comparison, the research team compared the measured performance of the GEHP in the field to the predicted performance of an electric heat pump while operating at the same conditions and delivering the same amount of cooling or heating.

Project Results

When providing heating, the monitored GEHPs demonstrated the heat recovery features and were shown to use less source energy than was predicted for a comparable electric heat pump. However, when providing cooling both monitored GEHPs used more source energy than was predicted for a comparable electric heat pump.

The annual cost of energy to operate GEHP 7 was estimated at \$3,268, which is roughly 10 percent more than the predicted cost to operate a comparable EHP of \$2,977. The annual cost of energy to operate GEHP 22 was estimated at \$3,094, which is about 50 percent more than the predicted cost to operate a comparable EHP of \$2,011. Although GEHP 22 was estimated to cost less to operate than GEHP 7, it provided less cooling and heating of the two GEHPs.

Because of the low rate of carbon dioxide (CO₂) emissions for electricity produced in California, both units were estimated to produce more CO₂ than was predicted for a

comparable EHP. However, if the national average CO₂ emission rate for electricity production was used in the comparison, the CO₂ emissions from the GEHPs would be nearly equal to that predicted for a comparable EHP. GEHP #22 consistently performed worse than GEHP 7 indicating that it may have been commissioned incorrectly or requiring maintenance.

The complete project report is provided in Appendix E.

Energy and Water Efficient Commercial Clothes Washers Using Polymer Bead Technology

California businesses, such as hotels, restaurants and athletic facilities, consume water, electricity, and gas to provide customers with clean laundry essential to operations. Reducing the consumption of these resources will help the state meet its goals for energy efficiency and greenhouse gas reduction, alleviate pressure on the state's water resources, and reduce costs for California business owners.

The polymer bead laundry (PBL) system is a commercial laundry system designed to reduce water and natural gas consumption without reducing cleaning performance. This new laundry system uses polymer beads to increase mechanical action and absorb soiling agents. The cleaning action achieved by the polymer beads requires less water and operates effectively at a lower temperature than a traditional clothes washing machine. Significant natural gas savings can be achieved by using the PBL technology since the water used by the system does not have to be heated.

Project Purpose

This project studied the potential resource and economic savings that can be achieved by replacing a typical commercial washing machine with the PBL washing system. The research goal is to produce a representative comparison between current laundry technology and the new system and provide useful data for evaluating the feasibility of the technology and for identifying barriers to its entry into the market.

The research team chose industrial washer extractor as the baseline technology used in the comparison analysis to the PBL system. The capacity of the baseline system is 60 pounds of laundry; the capacity of the PBL system is 65 pounds of laundry.

Project Results

The polymer bead technology successfully demonstrated effectiveness in significant gas and water savings relative to the baseline system, while using only slightly more electricity. An in-depth energy analysis shows that the net source energy use was reduced by about 63 percent and greenhouse gas emissions were reduced by nearly 90 percent.

Although the PBL system reduced operating costs, the capital investment was much higher than the washing machine using traditional hot water and detergent. An economic analysis showed that the PBL system would have to process at least 1,100

pounds of laundry per day to achieve the same net cost as the baseline system. This amounts to about 17 hours of operation per day. This outcome was identified as a potential barrier to widespread adoption of the polymer bead laundry washing technology.

The complete project report is provided in Appendix F.

Post-Assessment Verification and Analysis

The California Advanced Lighting Controls Training Program (CALCTP) is a statewide initiative with the goal of increasing the use of advanced lighting controls in commercial and industrial buildings to improve energy efficiency. Through proper installation, lighting controls improve energy efficiency, resulting in lower operating costs and a reduction in energy use. CALCTP trains and certifies licensed electrical contractors and state certified general electricians in the proper programming, testing, installation, commissioning and maintenance of advanced lighting control systems in commercial facilities.

Project Purpose

The research team conducted postassessment analyses of advanced lighting control system (ALCS) installations to verify overall system performance. Analyses compare the economic, energy and user acceptance impacts of projects installed by CALCTP-certified electricians versus projects installed by non-certified electricians.

Project Approach

The research team conducted four primary tasks: a literature review, data collection, data analysis and reporting. The literature review compiled existing knowledge of advanced lighting control systems (ALCS) capabilities, energy savings, installation cost, user satisfaction and the role of proper ALCS installation in achieving maximum benefits to end users.

Literature review results were used to develop data collection and analysis methods for each key research question. Data collection and analysis were conducted to determine ALCS capabilities, energy savings, installation cost, and user satisfaction. The research team compared calculated energy savings and actual energy savings for all surveyed ALCS projects. Actual system energy use relies on measured energy use collected at the site. The research team derived calculated energy use for pre- and postretrofit systems, is derived using assumptions identified in the literature review. To evaluate the difference in energy use for CALCTP certified and non-CALCTP certified ALCS installations, researchers used appropriate statistical methods are used (for example., ANOVA or analysis of variance and t-tests).

Various stakeholders were surveyed to evaluate the effect that the CALCTP program has on installation cost factors, including energy-use expenditures before installation, energy-use expenditures after installation and the installation labor rate. Various

stakeholders were surveyed to evaluate the effect that CALCTP certification had on end user satisfaction including the number of repeat customers, ease of lighting use by customer and overall customer satisfaction. End users were surveyed directly after the ALCS installation and two years after installation.

Project Results

Key economic findings of the project show that for non-CALCTP installed projects, the average labor cost rate compared to total costs was 53 percent; whereas, the average labor costs for CALCTP installed projects compared to total costs was 43 percent, or 10 percent lower. These data support that it is less costly (for example, installers take fewer hours) to use certified teams.

Key barriers to ALCS market penetration include missing or erroneous information about quality, payback and costs; dispersed decision makers, including owners, designers, installers, managers, and operators; business-as-usual inertia; rapidly changing energy codes; and the fast pace of lighting technology and design practice change.

Research conducted in this study has demonstrated that ALCS installations are not meeting the full savings potential and thus not giving commercial building owners the returns they should expect on investments. By improving and addressing limitations in the labor force conducting these installations, enhanced training can bring advanced lighting control system costs down, improve returns on investment, decrease pay-back lengths, and expand the market for ALCS technologies.

To further evaluate the CALCTP program, a pilot initiative using a bigger sample size with a consistent building stock with ALCS installations by both CALCTP and non-CALCTP installers is recommended. Ideally, the pilot program that would contain at least 30 CALCTP and 30 non-CALCTP projects to be statistically significant. During this study, the research team recommends that a research question to compare the effectiveness of the installations to targeted Title 24 savings be included.

The research team recommends that maintenance training be added to the CALCTP contractor certification program. Most projects struggled with end-user understanding and comfort with maintaining the ALCS. The authors recommended that CALCTP consider adding a maintenance element to its program both for business owners/operators and contractors on how to improve customers' comfort with the technology upon project completion.

The complete project report is provided in Appendix G.

CHAPTER 4:

Conclusions

Key Outcomes

By compiling published literature, best practices, and “common sense” recommendations for technology assessments into one program, the burden of providing comparable studies between institutions and researchers is standardized for CASE initiatives. Throughout this research, the emerging technologies that codes and standards bodies are interested in evaluating to understand if they are ready for inclusion in their programs have evolved. Best practices for how to conduct a robust, repeatable technology evaluation remains focused on four key areas:

- Market and economic analysis
- Assessment methods and tools
- Conducting a study
- Program reports and project documentation

The cross-section of outcomes for the five assessments conducted using the method provided in the program manual showed that technology ready-for-inclusion and not-yet-ready-for-inclusion in CASE initiatives can be assessed equally by this approach. Each demonstration followed equal market/economic analysis, metering and verification methods, field installation practices, and reporting.

Each assessment using the program manual pointed to areas that required more detailed guidance beyond the initial draft. These lessons were incorporated into the final version of the program manual. The research team anticipates the document requiring periodic updates to account for unforeseen field conditions that users will encounter.

Lessons Learned

The research team documented areas requiring additional guidance or specificity throughout the assessments or both. The lessons learned during this process indicate the program manual should require a periodic revision to align with new issues discovered in the field.

- Explicitly call attention to the effect of data logger memory length on the ability of the demonstration to gather uninterrupted data regardless of site restrictions for the ideal resolution of data.
- Include the option for side-by-side incumbent and emerging technologies operation to more accurately capture more accurately the energy savings attributed to the technology efficiency versus the user behavior and to better determine the variance in energy savings based on user behaviors.

- Investigate inherent differences in laboratory assessments versus field assessments to determine if a complementary program manual is necessary for laboratory assessments; or, if it is appropriate to include specific guidance for laboratory assessments in this program manual
- Include discussion of the pros and cons regarding installation labor payment and management. Potential benefits include streamlining the communication and demonstration chain of command to retain as much ownership of the demonstration as possible.
- Elaborate on the effect of the community on the technology demonstration.
- When a portion of a technology system can leverage pre-existing components of incumbent system, include the end-of-life and maintenance impacts in the technology selection considerations.
- Add a sub-section within the Technology Installation section addressing the commissioning process for typical emerging technology systems, and
- Add a subsection within the Technology Installation section addressing troubleshooting to define the initial troubleshooting process for emerging technologies to reduce required site visits and the associated costs.

Next Phase

Activities required to ensure the successful adoption and use of the CASE-QDP program include outreach and advocacy to create awareness of the program; continued use of the program by the research community; and evaluating the future research needs specific to the codes and standards stakeholder community.

After publication, the research team proposes to conduct outreach regarding the existence of CASE-QDP and program manual using the CLTC website and newsletter, as well as the California Energy Commission's Online Resource Center. Additional advocacy work will be focused on encouraging the adoption of the program manual as a mandatory part of lighting stakeholder's demonstration activities. Key lighting stakeholders include, but are not limited to, the California Energy Commission's Building Energy Efficiency Standards team, the California Energy Commission's Appliance Efficiency Regulations team, the California Public Utility Commission, the U.S. Department of Energy, California investor-owned utilities, municipal utilities, and manufacturers of emerging technologies conducting field assessments.

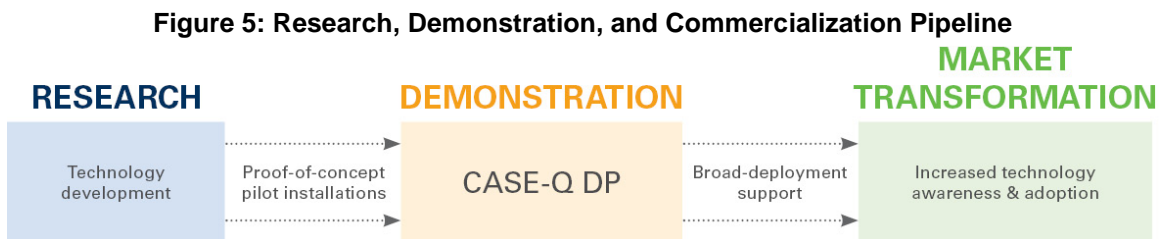
The research team will advocate for continued use of the program manual by the research community to a) gather feedback and refine the program; and b) establish a large body of research based on identical methods to feed into CASE work for future cycles. Images such as the Figure 4 will be used to communicate the concept of CASE-QDP and describe the benefit it will have to the state's energy reduction goals.



Source: UCD – California Lighting Center

Furthermore, evaluating future research needs for sister programs addressing additional stages of the research and development cycle; such as a laboratory-based program focused on technologies in the proof of concept stage.

The research team will promote the program by explaining the value in using consistent methods and procedures for conducting technology assessments which is to ensure quality and useful demonstration results (Figure 5). The outreach and advocacy will be conducted in a way to synchronize to the needs of the codes and standards process



Source: UCD – California Lighting Center

ABBREVIATIONS AND ACRONYMS

Term	Definition
ALCS	Advanced lighting controls
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
CALCTP	California Advanced Lighting Controls Training Program
CASE-QDP	Codes and Standards Enhancement-Quality Demonstration Program
COTS	Commercial off-the-shelf
Energy Commission	California Energy Commission
FDD	Fault detector and diagnostics
GEHP	Gas engine heat pump.
HVAC	Heating, ventilation and air conditioning
LED	Light-emitting diode
M & V	Measurement and validation
PBL	Polymer bead laundry
PIR	Passive infrared
RTUE	Roof top unit.
TLED	Tubular light-emitting diode

APPENDICES

Appendices A-G are published under separate covers.

Appendices A-B:CEC-500-2019-005-APA-B

Appendices C-D:CEC-500-2019-005-APC-D

Appendices E-G:CEC-500-2019-005-APE-G

Appendix A: CASE QDP Manual

Appendix B: Residential LED Luminaires and Lamp Replacements

Appendix C: Innovative Occupancy Sensors for Outdoor Applications

Appendix D: Fault Detection and Diagnosis

Appendix E: Gas-Engine Heat Pumps

Appendix F: Energy and Water Efficient Commercial Clothes Washers Using Bead Technology

Appendix G: Post-Assessment Verification and Analysis